mineral and vegetable matter predominating. The *ridge country* has an elevation of 90 to 150 feet above sea-level. The soil is a light sand, easily eroded, and intractable to most methods of improvement. This section represents one of the most important economic problems in the State. Calcareous marls have proved very beneficial, and it is believed by some fertilizer authorities that most of the area can be brought into a state of at least fair productivity.

Emory and Henry College, Emory,
Virginia.

DR. ROLLIN A. HARRIS' THEORY OF THE TIDES.*

BY

G. W. LITTLEHALES.

In a manner characteristic of a master of the facts of observation in relation to the tides and as the author of forms of computation for the analysis and classification of tidal records which constitute the greatest advance in practical tidal work since the introduction of the harmonic analysis, Dr. Harris has addressed himself to the task of outlining a tidal theory which shall account for the tides as they are actually observed to exist in nature. His preliminary studies of the causes of the tides led him to attempt to mark out in the oceans and other bodies of water such areas, or systems of areas, as are capable of independent oscillation in the same or nearly the same period as the tidal forces have, and in which it is possible for the tidal forces to cause the tide to mount up to a considerable amplitude; and then to obtain theoretical results with reference to these areas, under the supposition that the tidal forces are distributed over the waters of each system and that the times of elongation of the water particles are thus determined with reference to the tidal body. Having compared these theoretical results with the observed values, he announced that in most cases the dominant ocean tides have their origin in definite systems whose free periods of oscillation are very nearly those of the tidal forces, and that the time of high or low water in each is the time when the virtual work of the tidal forces upon the system becomes zero.

For the semi-diurnal tides, the systems pointed out are seven in

* Manual of Tides. Part IV A: Appendix No. 7—Report for 1900; Part IV B: Appendix No. 5—Report for 1904. } Coast and Geodetic Survey, Washington.

number, comprising the North Atlantic, South Atlantic, North Pacific, South Pacific, North Indian, South Indian, and South Australian. For the diurnal tides there are fewer systems. A system may comprise several regions of comparatively simple form, styled oscillating areas. If these areas could be partitioned off, each would have its free period of oscillation approximately equal to the period of the tidal body. From the tides thus produced are derived both stationary and progressive waves.

This is the keystone of the arch upon which is built the new explanation of the tides as they are found to exist in reality, and it is doubtless a doctrine that will prove to be of permanent value as an agency for advancing to a complete treatment of the actual causes of the tides. Philosophers have held that the tides of the ocean advance westward, tending to follow the moon in its apparent diurnal course in the heavens; and, according to this teaching, a westerly progression would be especially looked for in the southern seas where a continuous zone of water encircles the earth. But, as a matter of fact, there is a remarkable eastward progression in the South Pacific Ocean, and, as an illustration of the rational bearing of the author's theory, it may be said that this eastward movement is directly traceable to the boundary conditions surrounding the South Pacific oscillating system.

It is probable that the author was brought to recognition of the necessity for the existence of oscillatory motion sustained by the tidal forces by realizing the smallness of the effect of the forces demanded by the equilibrium theory in comparison with the ocean tides as they are known to be, and thus seeing that tides as great as the actual ones could only be produced by successive actions of the tidal forces upon systems, of such a nature that they would preserve the general character of their motion during several successive periods of the tidal body if the forces of attraction were to cease their action.

Of tides occurring in natural bodies of water, those most easily understood occur in bodies so small and deep that the equilibrium theory applies. To such cases Chapter 1, Part IVA, is directly applicable, as are certain sections in previous parts of the Manual, notably §§38-40, 42, Part I, and §§49, 50, Part II. For instance, we see (§3, Part IVA) that for a body of water not too shallow, lying under the equator and extending 172 sea miles east-and-west, the amplitude of the mean lunar tide at either end would be 0.08 foot; high water at the east end would be simultaneous with low water at the west end, and *vice versa*. The central meridian would constitute a nodal line along which there would be no rise and fall. For such

a body of water situated in any other latitude, the rise and fall at each end would diminish as the cosine of the latitude, while there would be some rise and fall on the south and north shores of the body. And so for any latitude north or south of the equator, a lake-like body will not possess a nodal line but a no-tide point. This point is the centre of gravity of the surface, and from it the cotidal line must radiate as straight lines.

The force diagrams, Fig. 1, Part IVA, furnish a ready means of computing the amplitude and time of tide for any small body of water whose depth is sufficiently great for causing its free period of oscillation to be but a small fraction of the period of the semi-daily or daily tidal forces. The equilibrium theory applies reasonably well to such bodies of water as Lake Superior, and the eastern portion of the Mediterranean Sea. On account of the expanse of the oceans, the water surface cannot arrange itself normal to the tidal forces in the period of a half day or a day, and so cannot obey the equilibrium theory. It is desirable, however, to have means of ascertaining the theoretical amplitude of the tide and the cotidal lines for bodies less extended than oceans, yet so large that the curvature of the earth's surface cannot be ignored; and §4, Part IVA, shows how such cases can be treated.

Chapter III, Part IVA, is devoted to a discussion of free oscillations in bodies having various geometrical forms. It illustrates the contour lines, including the nodal lines, and lines of motion, and shows how depth, horizontal dimensions, and period are related. The modes of oscillation obtained for a few simple areas have a much wider application than is at first evident; for if a thin, vertical wall be put in the place of any line of motion, the character of the motion will not be affected; and so a great variety of forms can be readily discussed. Chapter V supplements Chapter III, by experiments upon small bodies of water.

Chapter VI treats of small oscillations sustained by periodic forces, and has special reference to the prevailing ocean tides. The smallness of the equilibrium effect of the direct action of the tidal forces, if applicable to the oceans, can be inferred from the value already given for small bodies; which amounts to saying that the slope upon which the surface of the water temporarily lies when the maximum disturbing forces are acting in equatorial regions is, for the mean moon, only 0.017 of a second, or one vertical unit to about 12 million horizontal units. The equilibrium amplitude of tide for a deep body 1,720 sea miles long would not be ten times as great as the amplitude for a body 172 miles long, but something less, even if the

body were entirely enclosed by land. With the imperfect boundaries, and the prevailing ocean depths, it is evident that equilibrium tides must be small. The observed magnitude of the tide shows the necessity of oscillatory motion sustained by the tidal forces; and so the effect of a number of successive impulses is represented in any particular tide. For simplicity, canal-like areas are chiefly, but not exclusively considered. The body of water is supposed to be given in position, as upon a chart, and the forces, or local force arrows, of the diagram, Fig. 1, are readily found for any assumed Greenwich component hour. These are supposed to be properly scattered over the oscillating body and the times of elongation of the particles, *i. e.*, the times of high or low water at that loop, thereby determined.

Chapter VII consists of applications of the theory to the tides. In addition to the theory already developed numerous lemmas are laid down, which the conditions of the natural bodies of water require. Here the fundamental systems, shown in the world-charts designated as Figure 23 and 24, accounting for the dominant tides in nature, are pointed out and briefly described. Evidence of nodes and loops, or approximations to these, is also cited. In laying down these oscillating areas, certain requirements have to be filled at least approximately, *e. g.*, the free period as calculated by the body's horizontal dimensions and depth must approximate quite closely to the period of the tidal forces; if rectangular, the areas must be a considerable portion of a wave-length in width, and the more defective the lateral boundaries the broader must be the rectangle, in order that the forces may produce sensible tides.

Chapter VIII deals with tides in rivers, straits, bays, etc., its object being to explain some of the more local features of the tides.

Part IVB of the work is chiefly devoted to the descriptive and cartographic representation of the cotidal lines of the world, deduced in conformity with the theoretical considerations which have been unfolded as a means of obtaining a first approximation to the times of the principal ocean tides, and justified by the use of richer and more varied observations and a wider knowledge than have ever before been brought to bear upon this subject. The charts of cotidal lines are thirty-six in number, and relate to all parts of the seas of the world. The lines have reference to the *mean luni-tidal interval* and not the interval at *full and change* of the moon nor to the *M2 interval,* and the ranges given are *mean* or *average ranges* and not ranges at spring tides.

Upon referring to the world-chart of cotidal lines, it may be noticed that there are several points situated in different parts of the

world around which the tidal hours are represented to progress, completing a cycle of values in the period of the tidal oscillation. These are no-tide points, or places where the range of tide is nothing; and the regions in which they occur are called amphidromic, on account of the radiating cotidal lines having a cycle of values. They are caused by the overlapping of systems, by progressions due to secondary or dependent bodies of water into which a free wave progresses, and by the necessity for a gradual change between adjacent regions whose tides are not simultaneous; and they constitute a characteristic innovation in this great work, among whose chief fruits must be the benefits that will come from pointing out before the world, in a manner so orderly, the avenues of investigation and observation along which the further advancement of our knowledge of the tides is to be approached.

Nov. 23, 1906.

GEOGRAPHICAL RECORD.

AFRICA.

A Letter on African Languages.

Editor Bulletin:

Sir: The importance of language in relation to political and social aspects of the native question in Africa seems liable to be overlooked. The possibility of large groups of tribes, hitherto distinct and mutually antagonistic, becoming rapidly able and eager to understand each other in some common form of speech has apparently to be taken into account. Twenty-six years' contact with Swahili and various dialects of Eastern and Central Africa points so far to the conclusion that there is a remarkable degree of similarity, amounting in many important respects to substantial identity, in the grammatical structure of language over the whole vast area occupied by the Bantu races of Africa, from the Soudan to the Cape. And the stock of words common to all Bantu tribes, when recognised under their various dialectic disguises, will probably prove very considerable.

The Officials, Missionaries, Traders, Settlers and Travellers of various nationalities who are qualified to give help in testing this conclusion by personal and first-hand study of a Bantu dialect are naturally difficult to reach,—scattered in remote and often isolated spheres of work. It is, therefore, perhaps justifiable to ask publicity for the request, that persons so qualified and willing to accept and reply to a brief communication on the subject would send me their addresses at Fort Jameson, North Eastern Rhodesia. I should be grateful if foreign